Fig 1 Apparent Sequence in the Durness-Eriboll Region generally

Fig. 2 Coast N E of Village of Durness.

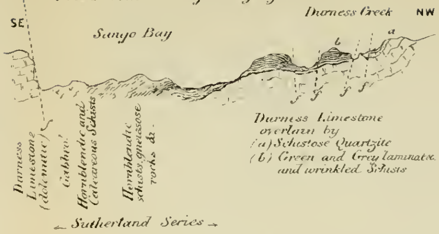


Fig 3. Near Loch Ceallna-Dail

Fig 4 General Section of Strata between the White Quartzite and the Durness Eriboll Limestone (Ant Sron)

Fig 5 Generalized Section. Slopes south-east of Ant Sron. (Loch Eriboll)

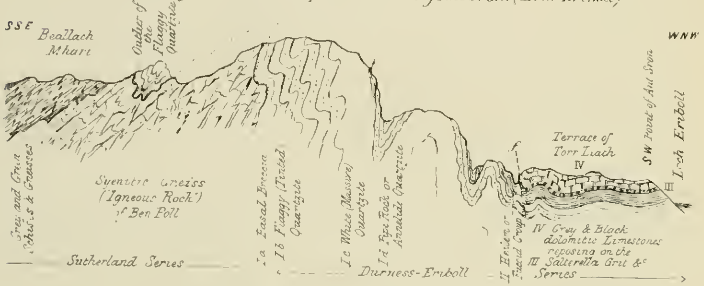


Fig 6 Undulated or Orthoclinic Strata with major and minor Amphiplexal folds)

Fig 7 Theoretical arrangement of folds in a Symmetrical Mountain Range

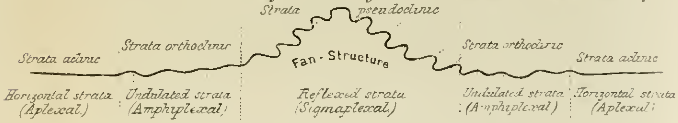


Fig 8 Theoretical arrangement of folds in a Symmetrical Mountain Complex

Fig 9 Theoretical arrangement of strata in a Denuded Mountain Complex

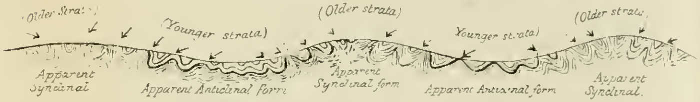
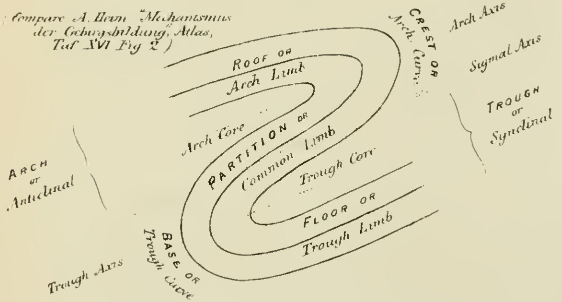


Fig. 10 Terminology of a Sigmaflexure or Reflexed Fold



THE

GEOLOGICAL MAGAZINE.

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No. V.—MAY, 1883.

ORIGINAL ARTICLES.

I.—The Secret of the Highlands.

By Prof. Charles Lapworth, F.G.S.

(*Continued from p.* 128.)

(PLATE V.)

VII.—*Difficulties in the Local Stratigraphy of the Oldest Geological Formations of Britain.*

IN those parts of Britain upon which all geologists are agreed with respect to the natural order of their ascending series of rock-formations, the stratigraphy is of a comparatively simple character. The beds are either gently inclined, or but slightly convoluted. The rules by which the original sequence of the strata is worked out have been settled by common consent. The nature and effects of those physical accidents which have affected the rocks subsequent to their deposition have long since been almost exhaustively worked out. The rules and conclusions thus developed are now-a-days part and parcel of the working material of every field-geologist worthy of the name.

These undisputed British rocks are, generally speaking, of Neozoic and Upper Palæozoic age. They afford an abundance of fossils; and, taught by the generally acknowledged truth of the maxim of William Smith, the stratigraphist, in those rare cases where continuous sections fail him, calls in the aid of organic remains, upon which he relies with almost as much assurance as upon the clearest visible physical proof.

But in proportion as we descend in the order of the British geological formations, the stratigraphical complexities increase; and, unfortunately, the means of unravelling these complexities begin to disappear in almost equal proportion. The strata grow more monotonous in their physical characters, and their fossils decrease most markedly both in abundance and variety. When finally we reach the Lower Palæozoic rocks, we find that in certain special regions (notably those of South Scotland, the Lake District, parts of Ireland, and Western Wales) their strata are intensely folded, crumpled, and often inverted. In these regions the stratigraphist, who has been trained among the newer and less complicated formations, becomes bewildered and deceived. He follows of habit and necessity the rules he found so serviceable in the less disturbed regions. He groups his strata in grand physical masses, and he settles the probable inter-relationships of these major groups by their *visible* order of superposition. The more extended has been his experience in British Neozoic geology, the more irresistible

in his eyes is this visible physical evidence. When, however, his survey is completed, he frequently discovers that his successive "formations," distinct as they appear lithologically, present a wonderful identity in organic remains through thousands of feet of vertical extent, when the fossils are regarded *en masse;* but show the most vital difference in their minor horizons, only a few yards apart, when the species are considered in detail. Such astounding palæontological phenomena he would scorn to acknowledge as probable or even possible in the Neozoic rocks. But the physical evidences at his command in these ancient convoluted strata appear unquestionable. There can, therefore, he imagines, be but one possible solution of the enigma. These palæontological difficulties are probably due in some mysterious way to the effects of migration, and may be safely ignored altogether. The outsider is left to draw for himself the implied conclusion: the dogma of "strata identified by superposition *and organic remains*" is of paramount consequence in the gently inclined, unbroken and varied recent formations; but in crumpled, dislocated and monotonous Lower Palæozoic strata such fossils as are discoverable are of no special stratigraphical value; the apparent superposition of the several recognizable rock-groups is the sole and sufficient clue to the original order of the beds.

This highly unsatisfactory method of eluding the difficulty I have long resisted to the best of my ability. In all those cases which I have myself been able to investigate, the asserted discrepancies between the physical and palæontological sequences have entirely disappeared wherever the strata admit of being worked out *zone by zone.* The difficulties of this task, however, are so great, and the natural tendency to rely upon *apparent* superposition so irresistible, that I feel assured that in some of its minor points my earlier work needs revision in the light of more recent discoveries. But the detailed palæontological sequence developed by the method of zones by myself several years ago among the convoluted Moffat rocks of South Scotland has been subsequently confirmed, as I shall show elsewhere, to an extent, and with a minuteness, which, even in my most sanguine moments, I hardly dared to anticipate.

In labouring to discover the original order of succession in such of the Lower Palæozoic rocks as are excessively convoluted, I find that the ordinary broad rules of British stratigraphy, as laid down in our text-books, are inadequate to the task. But they are not *superseded,* they are merely *supplemented* by a few additional principles applicable more especially to mountain regions. Even these additional principles are not new. Buried in the note-book of the mountain geologist, or in little studied foreign scientific publications, they have not yet made their way into our authoritative text-books.

I intended to publish some of my own conclusions upon the subject in the second part of my paper upon the "Girvan Succession," and to demonstrate their utility by showing how their application reduces to naturalness and symmetry the awkward-looking preliminary sketch-map of the region, as there developed almost wholly by the presently accepted rules of British stratigraphy. But the light

thrown upon some of the more obscure points in my study of the Durness-Eriboll district is so clear and vivid, that they fall most naturally into this place. Many of the points discussed in the following paragraphs (Pars. ix. and x.) will be found in the truly magnificent work of Professor Heim[1] upon the convoluted rocks of the Alps. For those not hitherto published, I hold myself responsible. The latter therefore are the only points open to the objection of being original or heterodox, and the attempt here made to summarize a few of the more essential principles of mountain stratigraphy, and to apply them to the investigation of the Highland region, may be, perhaps, received as a first essay in one of the most difficult and obscure departments of British geology.

But, before these principles can be introduced into this discussion, it will be necessary to demonstrate the inadequacy of the ordinary methods of stratigraphy as applied to the rocks of the N.W. Highlands; for, like the Upper Palæozoic and Neozoic strata, these rocks are often very gently inclined, dipping at angles varying from 60° to 30°, and sometimes as low as 10° or even 5°.

VIII.—*Application of the ordinary rules of British Lowland Stratigraphy to the study of the Durness-Eriboll Formations.*

The chief rules of British stratigraphy as applied to gently inclined rock-formations, which bear upon our present subject, may be thus shortly defined.

(*a*) Two successive series of gently inclined strata agreeing essentially in dip, strike, and apparent amount of convolution, are *conformable* to each other, and of these two conformable series, the physically overlying series is necessarily the *younger*.

(*b*) When the basal bed of a conformable series of strata rests immediately upon the surface of an underlying and discordant series, and contains included fragments of that underlying series, the two series are *unconformable* to each other, and the underlying series is necessarily the *older*.

(*c*) Faults or dislocations in gently inclined formations are normally *right lined*, and the plane of fracture normally hades or inclines in that direction in which the rocks have been *depressed.*

These are almost the only fundamental stratigraphical rules which have hitherto been employed in common by all parties in the study of the N. W. Highland succession. By the aid of the diagrams upon Plate V. and the descriptions given in the earlier paragraphs of the present paper,[2] the reader may easily gather for himself the results

[1] Mechanismus der Gebirgsbildung, A. Heim, Zurich, 1878.

[2] I have to apologize for the following errata in the previous part of this memoir:
- p. 122, line 1, for north-west, read north-east.
- p. 123, par. 3, line 10, for placing the whole in the Archæan, read regards the Silurian age of the Sutherland gneiss as open to doubt.
- p. 123, bottom line, for Microscopical Magazine, read Mineralogical Magazine, 1879, p. 137; 1881, p. 322; 1882, No. 22, p. 5.
- p. 126, line 7, for Hielem, read Heilim.
- p. 127, line 13, for VI. *b*. read IV. *b*.
- ,, line 20, for II. *c*. read I. *c*.
- ,, line 23, for II. *b*. read I. *b*.

of their application to the investigation of the geology of the Durness-Eriboll region.

(1.) When they are applied in the usual manner to the section of the region as a whole (see Fig. 1, Plate V.), they appear to demonstrate that the unaltered Durness-Eriboll series is *older* than the generally metamorphic Sutherland series, and that it is strictly *conformable* to the latter; the Durness-Eriboll Limestone forming the central member of the unaltered series, and graduating upwards through the Upper Quartzite and a massive group of "igneous rocks" into the typical altered rocks of the Sutherland series.

(2.) When they are applied to the most important sections in the Durness area [2] (see Figs. 2 and 3), they apparently demonstrate that there is no intervening igneous group lying between the conformable Durness and Sutherland series, but merely a thin seam of flaggy quartzite, which is only locally present.

(3.) When they are applied to the most easily interpreted section in the Loch Eriboll district, they apparently demonstrate that the unaltered Durness-Eriboll series, of which the Durness-Eriboll Limestone is the highest member, is *younger* than the generally metamorphic Sutherland series, overlying the latter with marked *unconformability* (see Fig. 5).

In brief, if these rules are to be our sole guides, it follows that

[2] As it has been suggested that the fossiliferous limestone of Durness is distinct from the generally non-fossiliferous limestone of Eriboll, from the fact that the two have "an absolute difference of composition" (Dr. Heddle, Mineralogical Magazine, 1881, p. 316); the limestone of the Eriboll-Kishorn line being throughout its whole range in the county "a very typical dolomite," while the Durness rock is a "fairly pure limestone;" I beg to submit the following analyses of four specimens of the Durness rock, collected by myself at the four localities named in the appended list. They may be looked upon as affording a fair idea of the chemical composition of the Durness beds, as they are traversed from west to east upon the ground. The specimens were analysed for me in the Chemical Laboratory of the Mason College, under the kindly personal superintendence of my colleague Dr. W. A. Tilden, F.R.S. From these analyses it would appear that while some of the zones of the Durness Limestone contain but a small proportion of magnesian carbonate, and may be defined as "fairly pure limestone," yet many of the beds, like those of Eriboll and Assynt band, are unquestionably dolomitic. The composition of the rock occurring in that special Durness zone, which, according to my own view, is repeated again and again in the Eriboll-Assynt area, is given in the last of these analyses, and this is clearly that of "a very typical dolomite."

Analyses of Specimens of Durness Limestone.

	a. (292)	*b.* (281)	*c.* (363)	*d.* (335)
Ca Co_3.	96·27	65·60	52·94	54·12
Mg Co_3.	1·40	26·20	43·71	45·90
Insoluble	2·01	6·85	2·43	trace
Fe.	?	?	?	?
	99·68	98·65	99·08	100·02

(*a.*) Specimen 292, from Eiland-Dhu, on Kyle of Durness.
(*b.*) Specimen 281, from hills near Loch Borralann.
(*c.*) Specimen 363, from near fossil-bed Balnakiel.
(*d.*) Specimen 335, from cliffs between Sango-bay and Smoo Cave.

the fossiliferous Durness-Eriboll series is composed both of two members and of three members, and the well-known Durness Limestone forms both the central and the highest of these. This strangely constituted fossiliferous series is both older and younger than the Sutherland gneiss, for it underlies the latter conformably, and it overlies it unconformably.

In all three cases the physical appearances are incontestable and admit of no dispute. It is needless to point out to the youngest tyro in geological field-work that we have here a complete stratigraphical dead-lock. It is impossible to reconcile these conflicting results as they stand. If no stratigraphical principles additional to those enunciated above are to be permitted in this discussion, the N.W. Highland controversy, which has already lasted for one generation, may well last for another, to divide and embitter geological investigators, and bar the way to those higher and more important geological problems that await solution.

Now in this Durness-Eriboll region the physical geologist, pure and simple, is in his own element. There are, practically, no fossils to complicate matters: the successive recognizable formations are totally distinct in petrological character, and the evidences of superposition are complete and unequivocal. And yet with all these advantages the accepted methods of British Lowland stratigraphy utterly break down. They land us in a set of conclusions so unnatural and absurd, that it would be ridiculous to suppose that any scientific man could entertain them for a moment.

Here, then, I reach from the purely physical side, precisely the same point I attained several years ago largely from the palæontological side: viz. the ordinary broad rules of British stratigraphy enumerated above, as applied to gently inclined strata, do not of themselves afford irrefragable evidence of sequence among the greatly convoluted older rocks *when the latter are regarded as grouped in broad masses*, and conclusions founded solely upon the testimony they afford under these circumstances are practically valueless.

In this desperate extremity, it may be suspected that our physical geologists will be tempted to look a little more closely into the matter, and see if a more detailed study of these rocks in the light of the discoveries made of late years in mountain regions will aid us in clearing up the difficulty.

In the following sections I have shortly summarized some of those more important points in the stratigraphy of convoluted rocks which bear upon the present question. For the sake of simplicity of treatment, I have merely investigated here that simplest hypothetical case in which the mountain strata are comparatively homogeneous, have been subjected to opposing pressures acting along parallel lines, and have consequently been looped up into symmetrical folds of infinite length. In order to avoid prejudicing my case, I have, where possible, selected my illustrations from standard authorities, especially from the classical work of Professor Heim.

IX.—*Essential Principles of Mountain Structure.*

(*a.*) *General Principles.*

1. All sedimentary strata were originally deposited in an approximately horizontal position, and they owe their present inclination, undulation, or contortion to the effects of lateral compression, or tangential thrust and counter-thrust of the exterior parts of the earth's crust, and the results of this lateral pressure in distorting the strata are most typically displayed in *mountain regions.*

2. Where the local force of compression is comparatively slight or ineffective, the originally horizontal strata are bent into a series of gentle undulations (normal flexures or amphiplexes) composed of alternate arches and troughs (anticlinal and synclinal folds), whose axes are normally vertical, and whose beds dip in opposite directions (*orthoclinic* or *amphiclinic* strata). These folds are of two kinds—major and minor, each major fold being generally made up of a series of minor úndulations (Fig. 6, Plate V.).

3. Where the lateral pressure is of excessive intensity, the anticlinal and synclinal waves become crushed more closely together into a series of much narrower folds, and the entire rock-mass loses greatly in horizontal extension, but gains proportionately in height, giving origin to what is known as a *mountain range,* the major fold forming the crest, and the harmonic minor folds constituting the flanks of the range (Fig. 7).

4. At the foot of a mountain range the inward thrust and the outward counter-thrust are approximately equal in amount, and opposite in direction, and the resulting folds are normal and regular (normal or amphiplexal folds). But as we proceed towards the centre of the range, while the thrust inward remains approximately the same, the counter-thrust outward is aided by the effects of the gravity of the mass above, and these two unequal forces are applied to the stratum obliquely with respect to each other. As a natural consequence, the axes of the rock-folds no longer remain vertical, but *slope obliquely outwards*—*i.e.* in that special direction in which the folding and ascending strata encountered the least resistance to their extension (Fig. 7).

5. In a simple and equal-sided *mountain-range* these phenomena being correspondingly developed upon the two opposite sides of the range, give origin to the well-known *fan-structure* (Fig. 7), seen in greatly denuded mountain forms, the younger beds upon the flanks of the range being reflexed and inverted in position, apparently dipping inwards in both directions below the older strata of the ridge above.

6. In a typical complicated *mountain-system* of vast antiquity (which may be regarded theoretically as a series of simple mountain ranges pressed more closely together), this special fan-like structure must be again and again repeated (Fig. 8), and after denudation has taken its full effect, its *newer* strata will of necessity be found in the apparent anticlinals, and its *older* strata in the apparent synclinal forms (Fig. 9).

7. Thus in the gently undulating rocks of the Lowland regions the visible dips of the strata are reliable indices of the original relations of the sediments (*Orthoclinic strata*); but in intensely folded mountain regions the dips have been generally inverted, and give false ideas of the original sequence of the beds (*Pseudoclinic strata*).

(*b.*) *Special Principles.*

8. In *Orthoclinic* or slightly folded rocks, each fold or undulation (*amphiplex* or normal fold) is composed of two members, an arch or anticlinal, and a trough or synclinal. In both of these the axis is vertical, and the strata dip in opposite directions (*Orthoplexal* or amphiclinic strata) (Fig. 7).

9. Where the compression increases in amount of force and obliquity of direction, as in the flanks of mountain chains, the amphiplex, or normal fold, becomes gradually transformed into an oblique sigmoidal or S-shaped fold (*sigma-flexure, sigmaplex* or *overfold*), both axes of which are inverted (Fig. 10), and its beds all dip in one and the same general direction (*Plagioplexal* or isoclinic strata).

10. Each *sigmaplex* or sigmoidal fold is also composed of two members, an inverted *arch* or anticlinal, and an inverted *trough* or synclinal, having an intermediary wall or *partition* which is common to both. Its various parts may be conveniently distinguished as follows (compare Heim, Mechanismus der Gebirgsbildung, taf. xvi. Fig. 2):—

Terminology of a sigmaplex or sigmoidal fold (*Overfold of Brögger*) (Fig. 10).

A. The arch or anticline.
A.[1] *Core* of the arch; *A.*[2] *Crest* of the arch; *A.*[3] *Roof,* or outer limb of the arch.
B. The Partition, or common limb.
C. The Trough or syncline.
C.[1] *Core* of the trough; *C.*[2] *Base* of the trough; *C.*[3] *Floor,* or outer limb of the trough.

x, Sigmal or Plexal axis; *y,* Anticlinal or Arch axis; *z,* Synclinal or Trough axis.

(*To be continued.*)

II.—Second Note on the Pebbles in the Bunter Beds of Staffordshire.

By Prof. T. G. Bonney, M.A., F.R.S., F.G.S.

In my brief paper published in this Magazine for 1880 (Decade II. Vol. VII. p. 404), I mentioned that pebbles of felstone were not uncommon in the Bunter conglomerate on the northern part of Cannock Chase. Since that time, as opportunity has occurred, I have been making a more special study of these pebbles, and think it may be worth while publishing a description of some of the commoner varieties, as a contribution to the lithology of this interesting deposit and a help to the determination of the question of the origin of its material. I believe that I have observed most of the varieties, which commonly occur in the district, but do not pretend